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INJURY BIOMECHANICS RESEARCH
Proceedings of the Eleventh International Workshop

NHTSA Data Base Filtering and Sampling Rates

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Introduction

The Biomechanics Group of the National Highway Traffic Safety Administation (NHTSA) maintains a data base of test results from Biomechanical tests conducted with NHTSA sponsorship. The data base contains the signals, primarily accelerations, recorded during an impact to a human surrogate. A standard set of signal processing is performed on each signal before any analysis is performed, although the original, unfiltered, "raw" data is still available for analysis. Recently it has been claimed that the standard processing "severely distorts" the signals. While no specific criticisms or suggested alternative processing have been made, the change of severe distortion merits examination.

The Biomechanics Data Base

The signals from approximately 130 tests using cadavers are currently in the Biomechanics Data Base. These signals, primarily acceleration histories, are given a standard processing prior to any analysis. This standard processing is:

1) 300 Hz low pass, 2 pole Butterworth filter

2) Subsampled to a 1600 Hz sampling rate

3) Filtered with a Finite Impulse Response (FIR) filter with the following characteristics:

Pass band	<	100 Hz
Stop band	>	189 Hz
Gain	=	-50 dB

It is this standard processing which has been criticized.

It is also important to consider the users of the data, i.e., what types of analysis will be performed with the data. The Biomechanic's Data Base is used primarily for two types of analysis:

a) Device development and analysis (e.g. crash dummies)

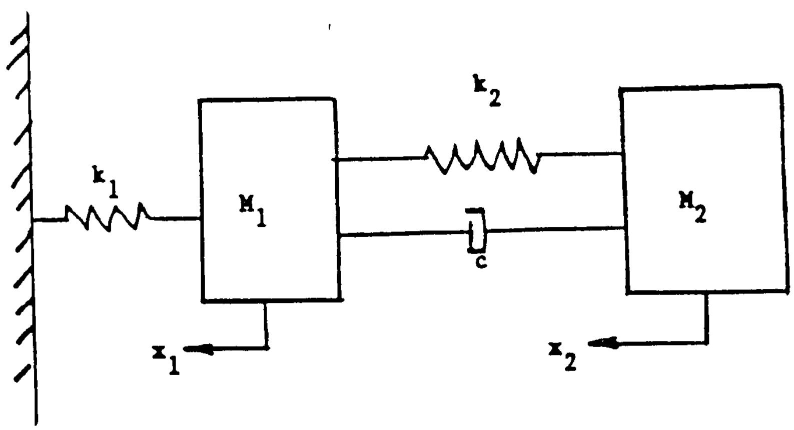
b) Injury criteria development and analysis

The answer to the question of are the data distorted, depends on for what the data will be used.

Effect of Filtering

Figure 1 shows a commonly used model of the thorax, the Lobdell model. This model simulates the response of the thorax to a frontal impact and also closely simulates the response of a common anthropometric dummy (the Hybrid III). This model was used for this study. The stiffness of spring k, was increased by a factor of 10 to 16,000 lbs/in. This was done to raise one of the fundamental frequencies of the system, and check for sensitivities to a higher frequency data.

THORAX



Thoracic Schematic

Governing Equations

$$\ddot{x}_1 = \frac{c}{M_1}(\dot{x}_2 - \dot{x}_1) + \frac{k_2}{M_1}(x_2 - x_1) - \frac{k_1}{M_1}x_1$$

$$\ddot{x}_2 = -\frac{c}{M_2}(\dot{x}_2 - \dot{x}_1) - \frac{k_2}{M_2}(x_2 - x_1)$$

Figure 1. Lobdell Model

where:

k_1 = skin stiffness = 1600 lbs/in (16,000 lb/in in this study)

k_2 = thoracic stiffness = 150 lb/in for $(x_2 - x_1) < 1.25$ inches
450 lb/in for $(x_2 - x_1) > 1.25$

c = thoracic damping = 3.00 lb-sec/in for $(x_2 - x_1) > 0$
7.00 lb-sec/in for $(x_2 - x_1) < 0$

M_1 = sternal mass = 1.0 lbm

M_2 = spinal mass = 60.0 lbm

Figures 2, 3, 4, and 5 show the signals predicted by the Lobdell model for a 20 mph 52 lb pendulum impact, a 16,000 lbs/in skin stiffness, and all other values as set by Lobdell. The signals shown are force to the sternum, sternum acceleration, spinal acceleration, and chest compression.

Injury Criteria

Recalling that one of the two primary uses of the data is to develop and analyze injury criteria, we ask the question does the filtering shift relationships so that injury criteria development is inappropriate? For this study we will speculate that there are four possible injury measures:

1) Force
2) Chest Compression
3) Sternal Acceleration
4) Spinal Acceleration

The Lobdell model was run at five speeds 5, 10, 20, 30 and 50 mph. Assume that 5 and 10 mph are cases of no injury, 20 mph is the transition between injury and no injury, and that 30 and 50 mph result in serious injury. It should be pointed out that there is no recommendation to use any of these injury measures, or impact speeds as actual injury indicators, rather this is typical of the types of studies that might use the data base.

The Lobdell model was used with these conditions, and the resulting signals were saved and filtered at different frequencies. In each case a 2 pole, low pass, Butterworth digital filter was used with cutoff frequencies of 1000, 500, 250, 100, and 50 Hz. The signal to be filtered had a sampling rate of 8000 Hz. For example, a 50 Hz Butterworth filter operated on predicted, unfiltered data sampled at 8000 Hz.

Figures 6, 7, and 8 show how the peak response for all five test conditions changed as a function of filter frequency for force, sternal acceleration, and spinal acceleration. Chest compression was not affected by any filtering done in this study. Force and sternal acceleration, which

Figure 2

Pendulum Force

PEND20.FRC

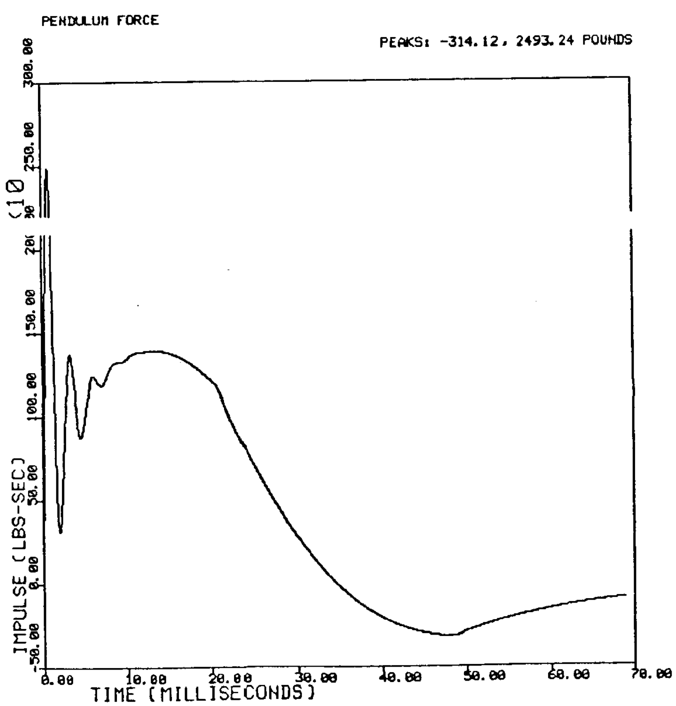


Figure 3

Sternum Acceleration

STERN20.ACC

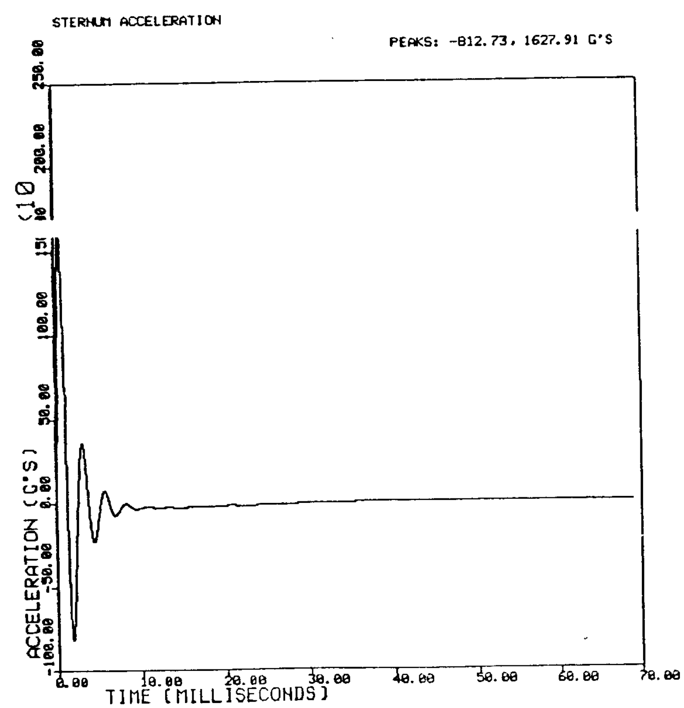


Figure 4

Spinal Acceleration

SPINE20.ACC

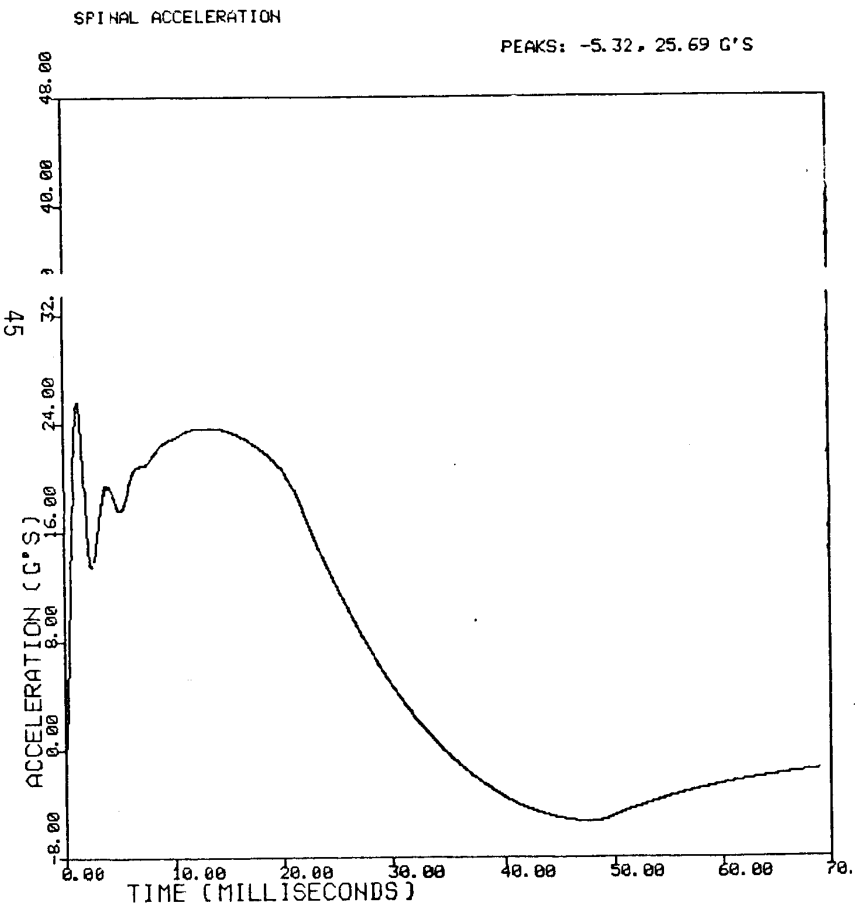


Figure 5

Chest Compression

CHEST20.CMP

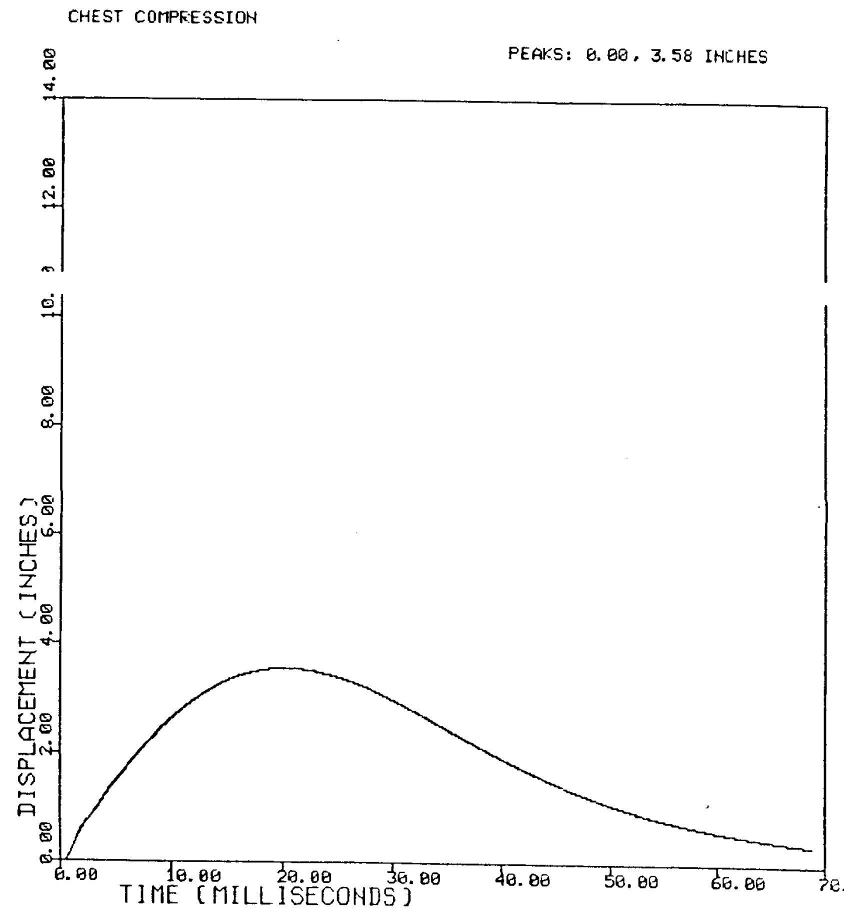


Figure 6

Effect on Peak Pendulum Force of Filtering

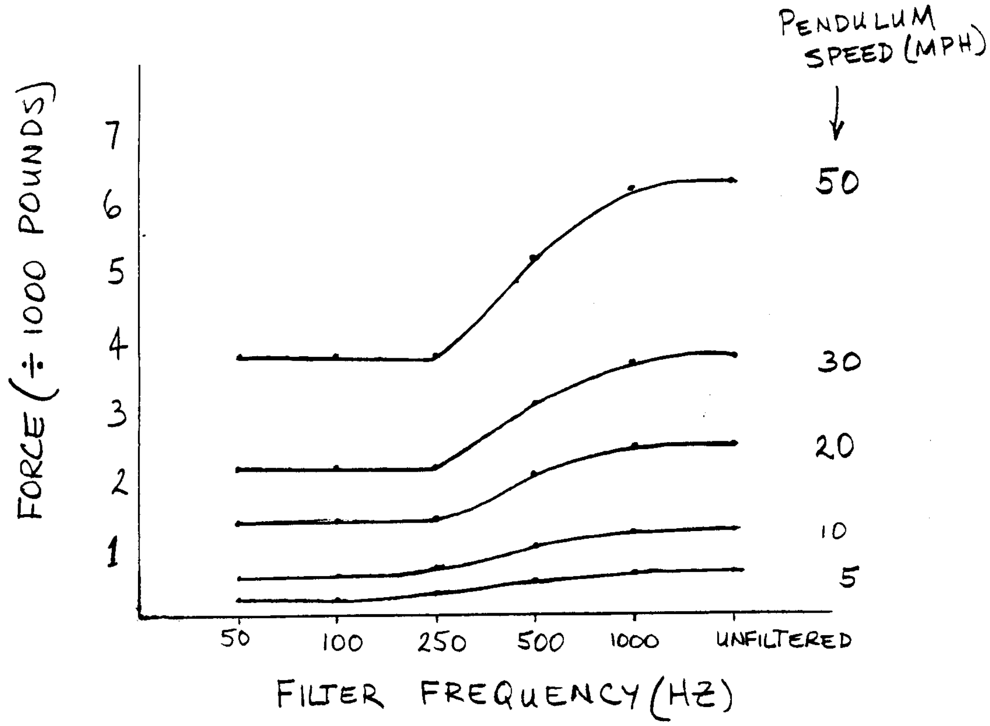


Figure 7 - Effect of Filtering on Sternal Acceleration

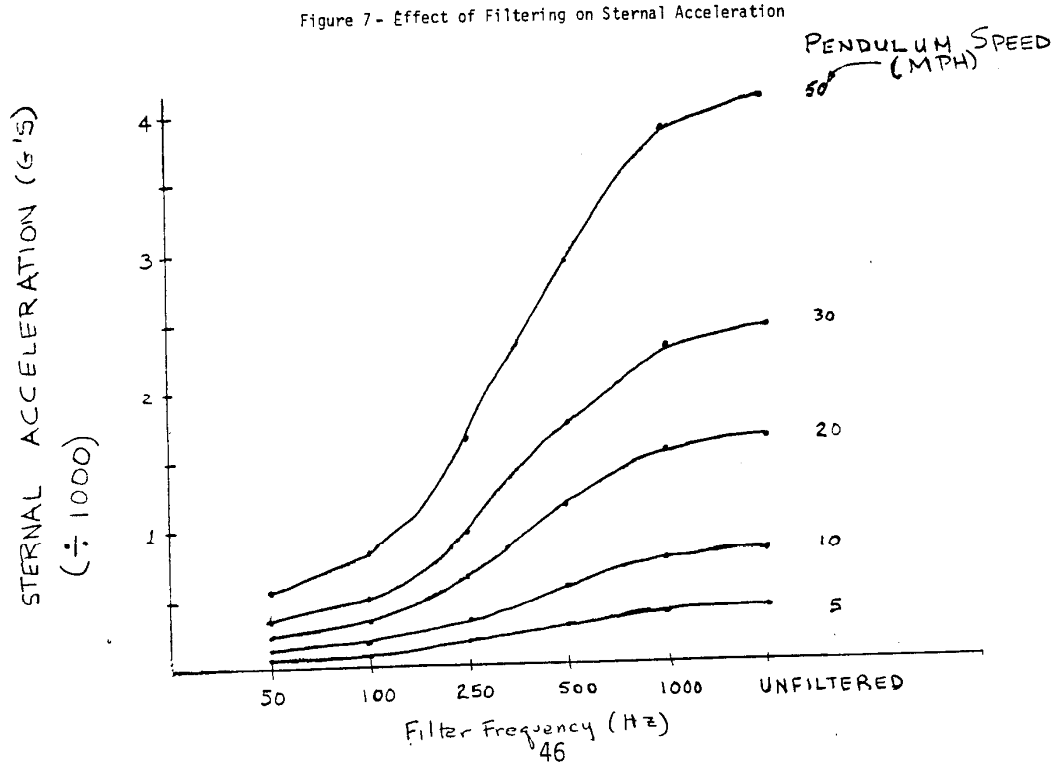


Figure 8

Effect of Filtering on Spinal Acceleration

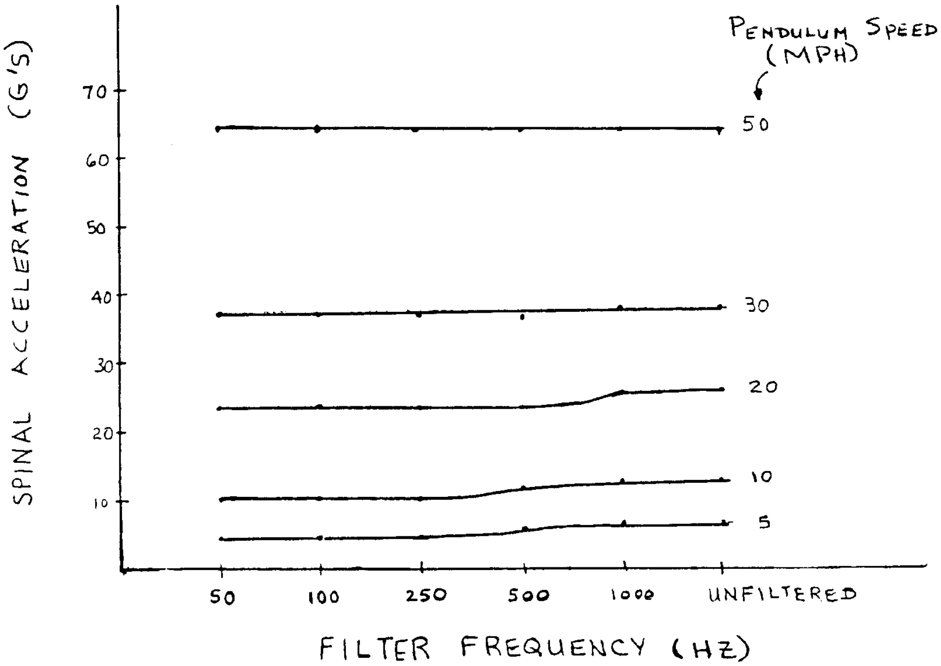
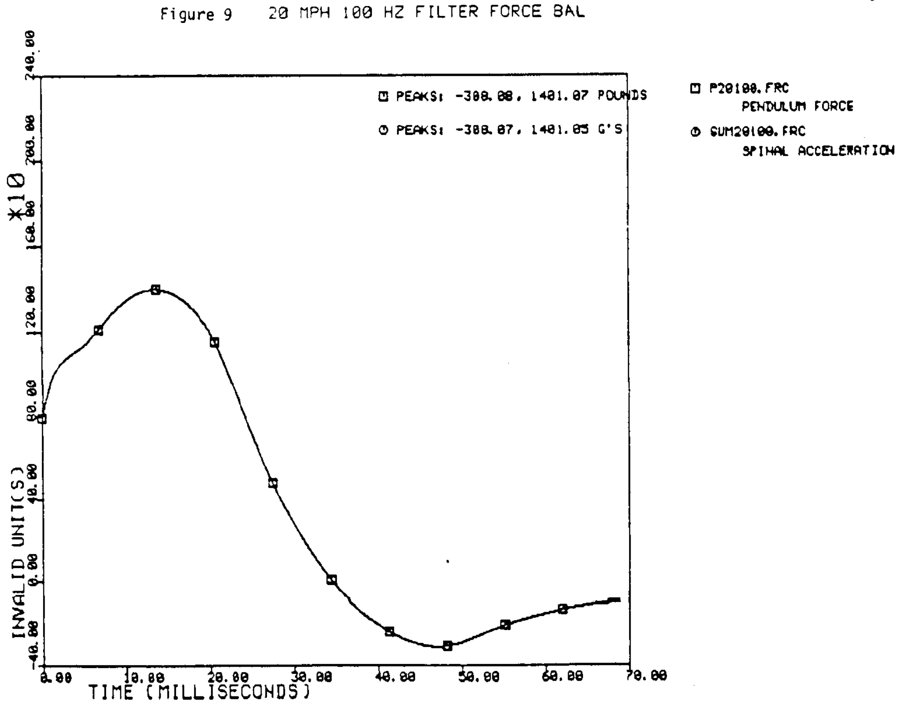


Figure 9 20 MPH 100 HZ FILTER FORCE BAL



contain the highest frequencies were, as expected, most affected by filtering. However, even with these higher frequency signals, the ratios of peak response between different impact speeds did not change significantly for the highly filtered data (50 Hz cutoff) compared to the unfiltered data.

Device Development

A test device such as a dummy must perform two jobs. The dummy must accurately record data needed for an injury criteria, and the dummy must properly interact with the crash environment, i.e., it must have the proper dynamic properties such as stiffness, damping, and mass. The Biomechanics Data Base is used to develop and analyze test devices. To test the affect of the standard processing on device development, the same signals from the Lobdell model used to analyze injury criteria were used. A force balance was then perfromed on the filetered data. That is, does

$$\sum F = \sum m_i \; a_i$$

where:

F = filtered force

M_i = the ith mass

a_i = the ith acceleration

If the force balance holds, i.e. if the sum of the forces equals the sum of the products of mass times acceleration, then use of the data for device development is appropriate. The basis for using the force balance as a criterion for filtering of data used in device development work assumes that someone designing a device would only have forces signals, and acceleration signals available. The acceleration signals could be integrated to yield velocities and displacements.

The development of the device depends on selecting the proper mass, stiffness and damping values. Given that accelerations are available from a finite number of points such as the sternum and the spine, and given that the masses to be used at each point are the design factor under study, then there are a unique set of masses which will produce the force balance throughout the time period of the signal. Thus, if filtering the signals changes the force balance, then using filtered data for device development would lead to improper inertial values.

Figure 9 shows the forces on the system overlaid on the sum of the products of mass time acceleration. The forces and accelerations were filtered at 100 Hz before any analysis was performed. Figure 10 shows a similar graph where the filter cutoff was 50 Hz. It can be seen in both Figures 9 and 10 that the force is identical to the sum of the mass-acceleration products, and thus that the force balance holds.

Because the force balance is true even with 50 Hz data, we may use filtered data to determine inertial properties. However, we have not yet examined the stiffness and damping properties of our proposed device. For the moment ignore damping and consider only stiffness, i.e., the function (hopefully linear, hopefully a constant) which describes the affect of zero order derivatives on the system. For impact biomechanics, the zero order derivatives represent displacement. Thus, if the displacement between the spine and the sternum is unaffected by filtering, then use of filtered data to design device stiffness is appropriate, ignoring for the moment damping affects. Damping is the function which describes the affect of first order derivatives, such as velocity, on a system. Damping may be considered as a method of describing how a system's stiffness changes as a function of velocity. Thus, if force-deflection data were available from an impact test run at one speed, it would not be possible to know how much stiffness was due to displacement affects, and how much was due to velocity affects. However, if force-deflection data was available from a number of impact tests run at different, known speeds, the change with velocity of stiffness (and thus damping) could be determined.

Recall that the section on injury criteria showed that chest compression, which is the displacement of the sternum relative to the spine, was unaffected by filtering. This was true for all speeds run ranging from 5 to 50 mph. On this basis then, it can be stated that use of filtered data to determine stiffness and damping properties of a test device is appropriate. After inertial properties have been determined, there exists a unique set of stiffness and damping properties which will give proper displacements. Because the data base is used to determine inertial, damping, and stiffness properties for device development, and it has been shown that these can be determined with filtered data, it is concluded that device development work using filtered data is appropriate.

Visual Comparison of Filtered versus Unfiltered

Figures 11 and 12 are graphs of two signals from the Biomechanics Data Base. On each graph is an overlay comparing the "raw", unprocessed data, and the data after it has received the standard processing previously described. The signals shown are the acceleration of the fourth left rib during a lateral impact. The reader may judge on his own the affect of filtering, though it should be remembered that these two signals were selected at random. While they are believed to be representative, no proof of this has been made.

Conclusions

While some have claimed that the standard processing applied to data in NHTSA's Biomechanic's Data Base distorts the data, no proof, nor basis

Figure 10

50 HZ FILTER 50 MPH FORCE BAL

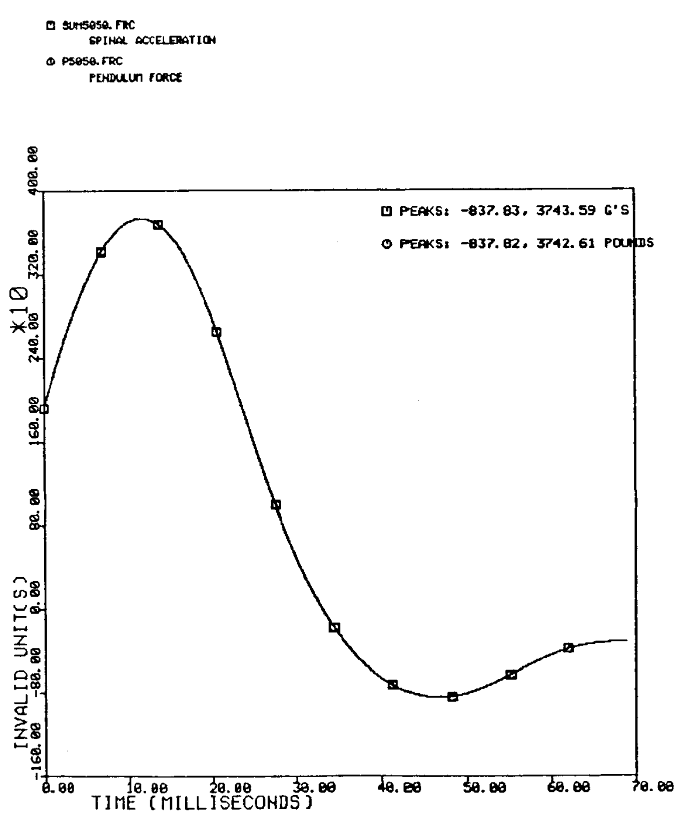
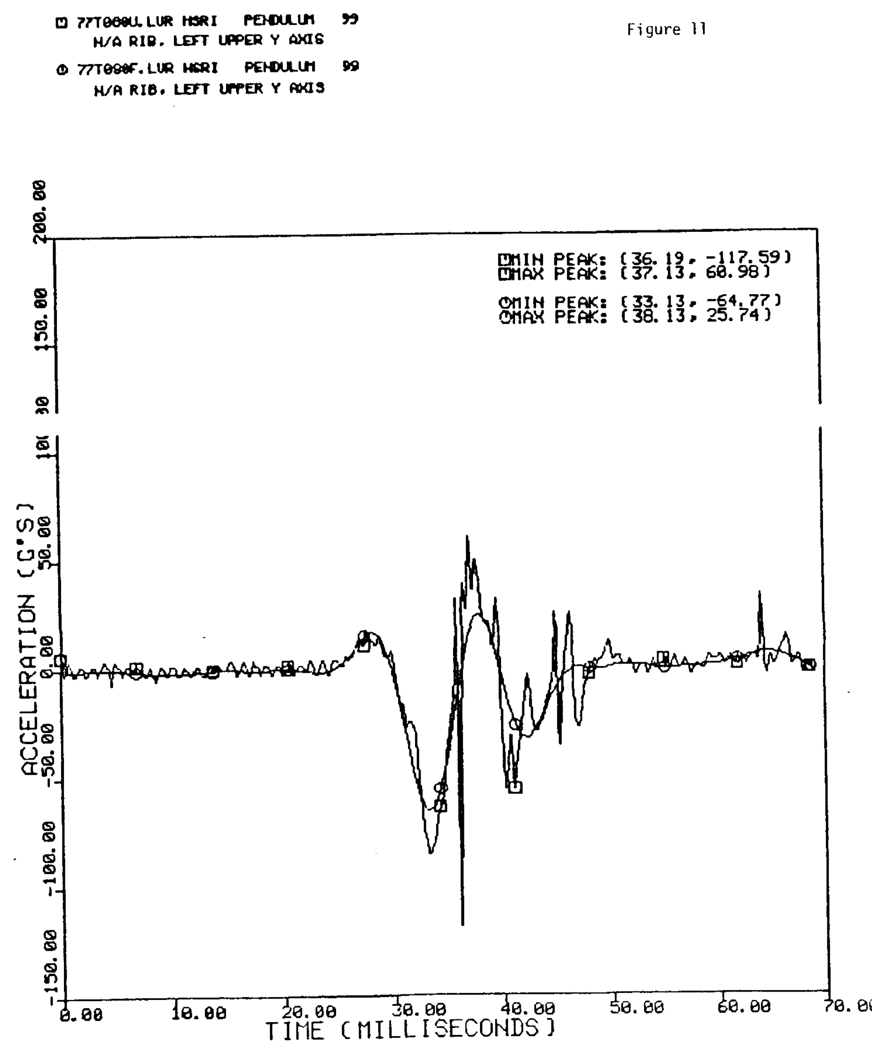
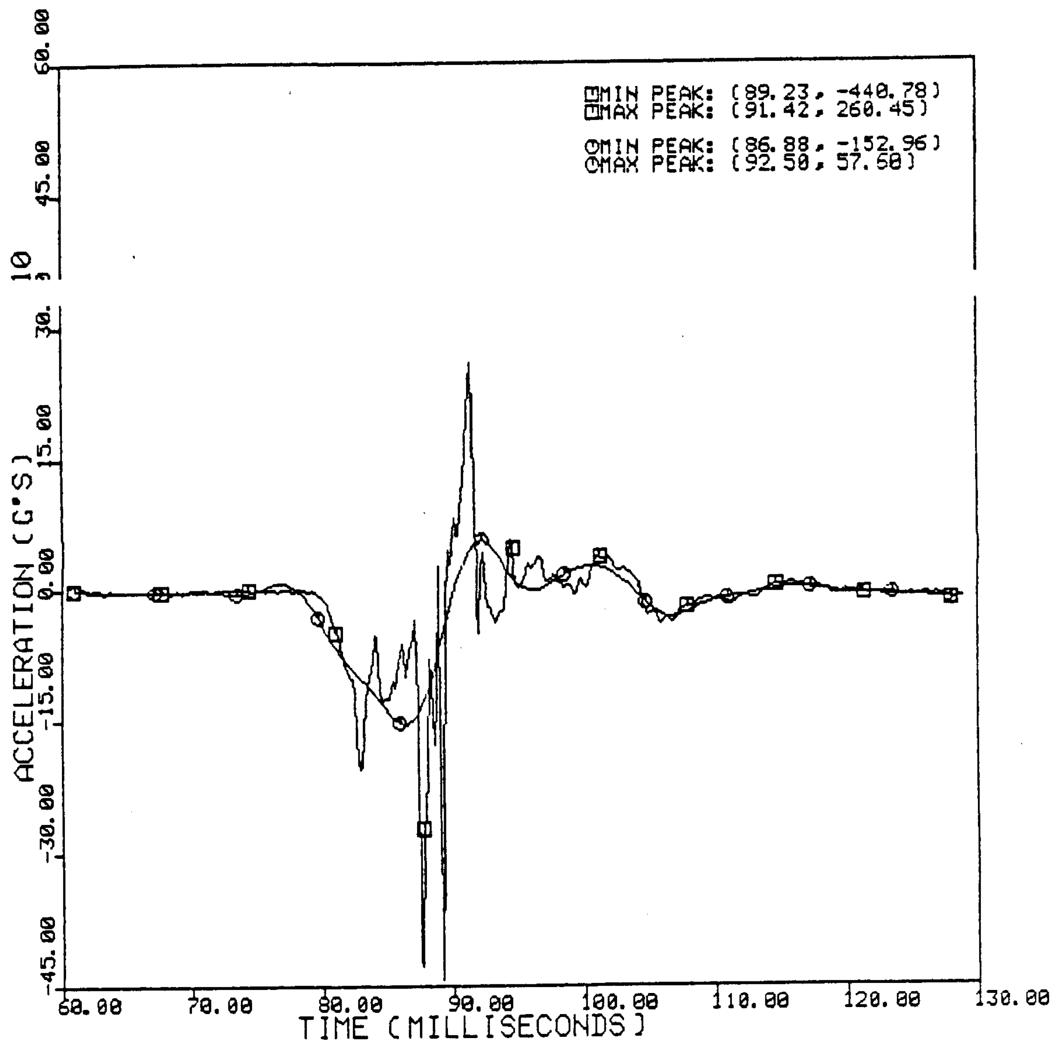


Figure 11



□ 77T092U.LUR HSRI SLED 99
H/A RIB. LEFT UPPER Y AXIS
⊕ 77T092F.LUR HSRI SLED 99
H/A RIB. LEFT UPPER Y AXIS

Figure 12



for this statement has been made. To a large degree, distortion is in the eye of the beholder depending on his desired use of the data. The Biomechanics Data Base exists primarily for use in injury criteria development and analysis, and for device (such as a crash dummy) development. It has been shown here that for these purposes the standard processing does not distort the data, and is appropriate.

This study is not the final word. There would be interest in proposed tests for our processing, and proof that some form of relevant analysis is inappropriate with our filtered and processed data. The "raw", unfiltered data is available, albeit somewhat more awkwardly, if it can be shown that a different processing is needed. Until then, we believe the standard processing applied does not distort the data.

REFERENCES

1. "Mechanical Simulation of Human Thorax Under Impact," Proceedings of 17th Stapp Car Crash Conference, 1973, Society of Automotive Engineers Paper #730982 by R.F. Neathery and T.E. Lobdell.